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NATURE OF SOVIET CAST ALLOYS

A. F. Silayev

[Comment: This report presents excerpts from the book Spravochnik po Litym Splavam (Handbook on Cast Alloys), by A. F. Silayev, published in Moscow in 1954 by Vodtransizdat. The information is presented under the following categories: I. Properties of Steel for Shaped Castings, II. Properties of Iron Castings, III. Substitutes for Casting Bronzes, and IV. Substitutes for Tin Babbitts.

A translation of the table of contents of the source is appended.]

I. PROPERTIES OF STEEL FOR SHAPED CASTINGS

Chemical Composition of Carbon Steel for Casting

Steel for shaped castings may be classified on the basis of chemical composition, structure, quality, or method of manufacture. Steels which contain all or some of the following amounts of admixtures are classified as carbon steels: up to 0.65 percent carbon, up to 0.5 percent silicon, up to 0.9 percent manganese, up to 0.1 percent sulfur, or up to 0.1 percent phosphorus. Steels containing greater amounts of these admixtures are known as alloy or special steels. Steels with up to 0.2 percent carbon are called low-carbon or mild steels, those with 0.20-0.40 percent carbon are medium-carbon steels, and those with a carbon content in excess of 0.40 percent are called high-carbon steels. If the total content of alloying elements in a steel is 3.0 percent or less, it is classed as a low-alloy steel. When the content of the alloying constituents is from 3 to 5.5 percent, the term medium alloy is used, while if the alloy content exceeds 5.5 percent, the steel is called high alloy.

GOST [State All-Union Standard] 977-41 for shaped carbon steel castings divides all steels into five grades on the basis of physical properties and carbon content. These steel grades for normal-quality casting are as follows: 15-4020, 25-4518, 35-5015, 45-5512, and 55-6010.

The first two digits in the grade designations refer to the average point carbon content, the second two digits to the tensile strength in kilograms per square millimeter, and the third two digits to the relative percentage elongation for a specimen with a fivefold gauge length.

If the method of manufacture is to be specified, appropriate code letters are prefixed to the grade: B for Bessemer, M for open hearth, and K for acid, e.g. K15-4020, B25-4518, etc.

The following are the grades of high-quality steel for casting: 15-4024, 25-4522, 35-5019, 45-5516, and 55-6012.

Moreover, there are also the following grades of steel for special-quality casting: 15-4028, 25-4525, and 35-5022.

Steel for shaped casting may be produced by any method: Bessemer, electric furnace (arc, high-frequency), etc. The silicon and manganese content in all of the above-listed three groups of steels is limited by GOSTs to a range of 0.17-0.37 percent for silicon and 0.50-0.90 percent for manganese.

It is recommended that the phosphorus and sulfur content of acid and basic steel for normal-quality casting not exceed 0.05 percent each, and not exceed 0.04 percent for special-quality casting. In normal-quality Bessemer steel, the phosphorus content should not be over 0.09 percent, while in high-quality steel it should not be over 0.06-0.07 percent. In castings subject to welding, the following admixture limits are recommended: carbon 0.25-0.35 percent, silicon up to 0.60 percent, phosphorus not over 0.05 percent, sulfur not over 0.04 percent, and manganese not over 1.10 percent. Shaped steel castings which are to be welded must have an increased silicon and manganese content, but should not exceed the limits established for carbon steels.

Typical Uses for Castings

The uses to which carbon steel castings are put in the shipbuilding industry are listed in the following table (Maritime Registry USSR, 1952, Central Planning and Design Bureau-2, and other sources).

Standard Parts Group	Steel Grade, GOST 977-41	General Application	Specific Cast Parts
A	25-4518	Lightly stressed parts whose dimensions are based on structural and technological considerations	Flywheel fittings; handles; board hawses; side light frames, bolt bars; hinges; draining, ballast, and scupper fittings; bulkhead stuffing boxes; hand-driven gears; rollers; lightly stressed block shells; heavy thrust bearing check clamps; crosshead slides; lightly stressed machine-driven gears; lightly stressed machine stands and frames; pilot wheel pedestals; pedestal chocks; guardrail supports; door assemblies, canting frames, etc.
B	25-4522 or 35-5015	Vital castings operating under considerable static or evenly applied stress, impact stress, or at pressures over 10 kg per sq cm	Saturated and exhaust steam fittings in pressure oil mains and high-pressure fire lines; covers for heat-exchange apparatus; flanges; Kingston valve flaps; cold-hardening equipment; axe heads; hawse pipes; deadwood pipe bushings; rudder stuffing boxes; deadwood pipes; shaft bossings; rockers and rudder quadrants; flukes; intermediate and thrust bearing housings; reducing and worm gear housings; auxiliary apparatus turbine housings; screw propeller hubs; steam boiler collector parts; machine foundation frames and pedestals; anchor brake plates; engine cylinders; drive gears for auxiliary machines and equipment;

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Standard Parts Group	Steel Grade, GOST 977-41	General Application	Specific Cast Parts
			reduction-gear wheels; eccentric yokes; windlass sprocket wheels; windlass plates and drums; boat davit supports; loading boom supports; steam hydraulic and hydraulic press stands; forge stands etc.
C	35-5015	Especially vital castings subject to impact loads and vibration; operating under a 400°C temperature and at high pressures	Stems; screw shaft brackets; rudders; rudder frames; rudder heads; boat davit supports and stands; hawse pipes; valve housings and valve boxes for superheated steam; screw propellers; propeller blades; crank and head bearings; nozzle housings; diesel cylinder caps, etc.
D	25-4522, 35-5015, or 35-5020	Vital castings for steam turbines	Steam turbine cylinders and rings, valve housings, reducer-gear housings, diaphragms with cast vanes, etc.
E	40G-L	Especially stressed parts and parts subject to wear	Large cylindrical gears, anchor chains, etc.

When in low-temperature service, carbon steel castings are unsatisfactory because of their sharp decrease in plasticity. For example, at 60 degrees below zero centigrade, the resilience of steel with 0.25-0.30 percent carbon is about one kilogram per square centimeter. It is recommended that alloy steel be used in cast parts in service below 30 degrees centigrade.

Chemical Composition of Alloy Steel for Shaped Casting

As was indicated above, steel with an increased content of the usual admixtures, or with a content of special admixtures, is known as alloy steel.

Alloy steel has the following substantial advantages over common carbon steel:

1. Improved physical and mechanical properties not only at ordinary but also at high and low temperatures;

2. Longer service and less chance of failure in service;

3. Increased suitability for deep hardening, thus considerably increasing the strength of large parts;

4. Suitability for deep drawing, which allows a decrease in internal structural stresses without a great loss in strength of hardness, thus assuring increased plasticity and high service reliability with great variable loads;

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5. Considerably greater corrosive and wear resistance in sea water, superheated steam, and other aggressive media.

The following alloying elements are used in special steels: manganese, chromium, nickel, copper, molybdenum, vanadium, titanium, tungsten, zirconium, cobalt, and others. Most widely used are manganese, chrome-nickel, and chrome-nickel-molybdenum steels.

Much practical use is made of chromium and copper alloys. Steels with small amounts of alloying elements -- chromium, nickel, and molybdenum steels, the so-called "low-alloy steels" -- are widely used.

The symbols for identification of alloying elements in steel grades has been standardized as follows:

Carbon	U	Chromium	Kh
Manganese	G	Nickel	N
Silicon	S	Molybdenum	M
Tungsten	V	Copper	D
Aluminum	Yu	Phosphorus	P
Vanadium	F	Cobalt	K
Titanium	T	Sulfur	--

The first digits in alloy-steel grade designations refer to the average point carbon content, e.g., 40G or 30Kh. In tool steels, the carbon content is indicated in tenths of one percent and follows the letter, e.g., U7 or U12.

The letters to the right of the figures indicating carbon content identify other alloying elements in the steel, e.g., 40KhGS. The digits following the letters indicate average percentage content of the alloying element, if over one percent, e.g., 40Kh2G.

The suffix "A" identifies the steel as being of high quality with a limited sulfur and phosphorus content, e.g., 40KhGSA. The prefix "E" indicates that the steel was produced in an electric furnace.

Single-Element Low-Alloy Steels

1. Manganese Steel

A manganese content of up to 1.10 percent in steel noticeably increases the strength, hardness, and resiliency of the ferrite and decreases its plasticity.

The hardenability of manganese steel is not significantly increased by heat treatment, thus it cannot be used in large castings having wall thicknesses of over 100 millimeters.

The principal asset of manganese steel castings is their high resistance to wear. They are used for excavator shovel parts and various other low- and medium-weight castings which may be hardened in an air stream or liquid.

Manganese in the form of blast-furnace ferromanganese is not a deficient alloying element.

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The recommended manganese steel composition is carbon, 0.20-0.45 percent, and manganese, 1.0-1.7 percent. Carbon steel with a higher manganese content is characterized by greater strength and wear resistance.

The carbon and manganese content in steel is determined by the desired physical properties of the casting and its wall thickness. If the part is to have high plasticity, normal strength, and thick walls, the manganese content must be greater and the carbon content lower. If, on the other hand, high strength and normal plasticity are required, the manganese content must be decreased and the carbon content increased. In every case the manganese and carbon content must be such as to assure a pearlitic or sorbitic structure.

The chemical composition of manganese steels used in wear resistant castings is as follows:

Grade	Composition (%)		
	Carbon	Manganese	Silicon
25GL	0.20-0.30	1.10-1.30 1.35-1.55 1.70-1.90	0.30-0.45
30GL	0.25-0.35	1.05-1.35	0.30-0.45
40GL	0.35-0.45	1.35-1.55	0.30-0.45

2. Nickel and Chromium Steels

Nickel increases the strength and hardness of ferrite without decreasing ductility. Nickel steel is easily machined. Nickel sharply increases the hardenability of steel and assures uniformity of physical properties throughout the body of the casting. When nickel is used as the sole alloying element, its effect on steel is somewhat weaker than when used in combination with other admixtures; therefore, the use of nickel steel in the casting industry is limited. Nickel steel has high fatigue limit and resiliency. Nickel-steel castings are characterized by a very high structural and physical uniformity as well as by a high resistance to corrosion by sea water.

The usual chemical composition of nickel steel used for casting is carbon, 0.20-0.40 percent, and nickel, up to 3 percent. A nickel steel of this composition is recommended for screw propellers and paddles for ice breakers and long-range ships.

Chromium increases the strength, wear resistance, and hardenability of steel. By regulating the chromium and carbon content, it is possible to improve the physical properties of the steel.

The usual composition of low-alloy chromium steel used for casting is carbon, 0.35-0.45 percent, silicon 0.25-0.45 percent, manganese 0.6-0.8 percent, and chromium 0.7-0.9 percent.

In parts subject to wear it is recommended that the carbon content be increased to 0.60 percent and the chromium content to 1.5 percent. Steel containing 5 percent chromium, up to 0.20 percent carbon, 0.4-0.6 percent manganese, and up to 0.3 percent silicon possesses high corrosion resistance and is used for diesel heads in high-speed, ocean-going ships.

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Low-alloy chromium steel is used in castings with wall thicknesses of up to 75 millimeters and which are subject to great wear, high temperatures, or gaseous, corrosive atmospheres. Chromium steel castings have a relatively small plasticity, although higher than carbon steel castings.

Chromium steels with copper and nickel, molybdenum, or other admixtures possess many desirable properties and are therefore finding ever increasing use.

3. Silicon Steel

A silicon content in excess of 0.4 percent increases the strength of the ferrite and the hardenability of the steel, improves its physical properties, and increases its resistance to wear. Silicon steel is used in castings having high magnetic properties.

Low-alloy silicon steel for casting may, for practical purposes, be divided into two groups: low-carbon steel with 0.1-0.2 percent carbon and up to 1.0 percent silicon; and high-carbon steel with 0.40-0.50 percent carbon and 1.4-1.6 percent silicon.

High-carbon silicon steel is used for such wear-resistant castings as bridge crane rollers and pulverizer gears.

Because of their low flowability, silicon-steel castings tend toward hot and cold fractures and blow holes. Therefore, in designing silicon steel parts it is necessary that wall thickness be uniform and that there be no sharp edges and no stress raisers.

4. Copper Steel

Copper increases the strength, hardness, plasticity, and resiliency of steel, and the resistance of castings to atmospheric and salt-water corrosion. The effect of copper upon steel structure is analogous to that of nickel.

The optimum chemical composition of low-alloy copper steel is about 0.15-0.30 percent carbon and 1.25-1.75 percent copper. The good physical properties of copper steel together with its good casting properties and low cost are responsible for its wide use in the machine and shipbuilding industries. The belief that copper was responsible for red-shortness in steel has not been corroborated.

High-carbon copper steel with 1.35-1.60 percent carbon, 0.85-1.10 percent silicon, 0.7-0.9 percent manganese, 1.5-2.0 percent copper, 0.4-0.5 percent chromium, not over 0.1 percent phosphorus, and 0.06 percent sulfur is widely used in casting engine crankshafts.

5. Molybdenum and Vanadium Steels

Molybdenum imparts increased strength, hardness, hardenability, and machineability to steel. The chemical composition of low-alloy molybdenum steels lies generally within the range of 0.2-0.4 percent carbon and 0.2-0.5 percent molybdenum. Molybdenum steel is used in turbine and boiler building.

Vanadium considerably decreases structural disuniformity, refines the grain, improves the physical properties of steel, and is a very good reducer. Large castings from low-alloy vanadium steels are distinguished by their structural uniformity and fine grain. At room and low temperatures, vanadium increases the resiliency of steel. Therefore, vanadium steel castings are recommended for service in the north.

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The chemical composition of low-alloy vanadium steel lies within 0.25-0.45 percent carbon and 0.20-0.80 percent vanadium.

Because of its good physical, structrual, and casting properties, vanadium steel is used in thin-walled, complex castings.

Binary Low- and Medium-Alloy Steels

1. Chrome-Nickel Steel

Content of chromium and nickel imparts many favorable properties to steel: increased strength, plasticity, and resiliency, hardenability, and improved resistance to wear.

The recommended composition of chromium-nickel steels is as follows: carbon, 0.3-1.0 percent; manganese, 0.6-1.0 percent; silicon, 0.3-0.7 percent; chromium, 0.5-2.0 percent; and nickel, 1.0-4.0 percent: As the carbon (within the above range), chromium, and nickel contents are increased, the strength of the steel rises.

Chromium-nickel steel is used for casting parts subject to abrasive wear, impact loads, and alternating tensile and compressive stress such as excavator shovel parts, which must have high strength at increased temperatures.

Steel containing 0.41 percent carbon, 0.58 percent manganese, 0.29 percent silicon, 2.00 percent nickel, and 0.87 percent chromium is suitable for casting highly stressed gears, winch drums, etc. This steel is also used for casting vital complex parts, and parts with walls up to 200 millimeters thick. It should be noted that for reasons of nickel economy some plants use steel with an inverse proportion of nickel and chromium: 0.2-0.25 percent carbon, 2.5-2.0 percent chromium, 1.0-1.5 percent nickel. Such steel possesses high strength and plasticity.

The chemical composition of low-alloy chromium-nickel, nickel-molybdenum, and chromium-molybdenum steels for casting are as follows:

Steel Grade	Chemical Composition (%)							
	C	Mn	Si	Cr	Ni	S (max)	Mo	P (max)
37KhNL	0.35	0.80	0.40	0.94	1.30	--	--	--
KhN2L	0.39	0.86	0.37	0.67	1.78	0.04	--	0.05
KhN2L	0.40	0.52	0.37	1.00	2.39	--	--	--
30NML	0.32	0.70	--	--	1.35	--	0.32	--
30KhML	0.30	0.80	0.40	0.80	--	--	0.20	--
30KhML	0.27	--	--	1.00	--	--	0.50	--
40KhML	0.39	0.81	0.39	0.69	--	--	0.43	--
20Kh2ML	0.20	0.68	0.37	2.05	--	--	0.50	--

2. Nickel-Molybdenum Steel

Nickel-molybdenum steel has high strength, plasticity, and ductility at normal and high temperatures, and is easily hardened.

The admixture of molybdenum to nickel steel increases its hardenability and resistance to creep, and decreases its temper brittleness. The chemical composition of low-alloy nickel-molybdenum steel generally lies within the following range: carbon, 0.20-0.45 percent; nickel, 1.2-1.8 percent; and molybdenum 0.2-0.4 percent.

Low-alloy nickel-molybdenum steel is used for large, complex castings subject to extreme stress or high temperatures.

3. Copper-Chromium and Nickel-Vanadium Steel

Copper facilitates the dispersion hardening of steel, thus increasing the strength, plasticity, and resiliency of castings, especially in the presence of chromium.

The composition of copper-chromium alloys is as follows: carbon, 0.15-0.30 percent; silicon, 0.25-0.35 percent; manganese, 0.60-0 80 percent; copper, 1.30-1.50 percent; and chromium, 0.6-0.8 percent.

Such steel serves as a substitute for many castings made of chromium-nickel-molybdenum steel and is finding ever increasing use.

The admixture of vanadium to nickel steel facilitates the attainment of fine granular structure in thick-wall sections. Vanadium also increases strength, plasticity, and resiliency.

The chemical composition of low-alloy nickel-vanadium steel generally lies within the following range: carbon, 0.20-0.40 percent; nickel, 1.2-1.6 percent; and vanadium, 0.15-0.25 percent.

Nickel-vanadium steels are used in vital and complex castings subject to low temperatures (down to 70 degrees below zero centigrade).

<u>Multicomponent Steels</u>

The concurrent beneficial effect of two or more alloying elements on the physical properties of structural steel is due first to the positive effect of each of the elements on the primary and secondary crystallization of the metal, and second to the neutralization of any harmful effects of one element by another. For example, nickel in chromium steel deters granular growth and improves the ductility of the steel, increases resistance to fatigue, etc.

The admixture of various alloying elements improves steel hardenability. Thus, molybdenum and vanadium in chromium-nickel steel, increased carbon content in chromium-molybdenum steel, etc., make it possible to improve some of the physical properties of heavy-weight castings.

1. Manganese-Chromium-Silicon Steel (Chromansil)

Manganese-chromium-silicon steel has good hardenability and physical properties. The average chemical composition of this steel is: carbon, 0.20-0.45 percent; silicon, 0.5-1.0 percent; manganese, 0.7-1.5 percent; and chromium, 0.5-1.0 percent.

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Low-alloy manganese-chromium-silicon steel is one of the high-grade steels and is used for castings subject to impact, wear, and high stress. However, castings made of this steel are coarse grained and relatively dis-uniform in structure. Consequently, many plants generally alloy this steel with vanadium.

2. Manganese-Silicon-Chromium-Vanadium and Chromium-Nickel-Molybdenum Steels

The introduction of up to 0.12 percent vanadium into manganese-chromium-silicon steel improves the deoxidation and primary crystallization of the steel and increases its structural uniformity in large castings.

The steel has good hardenability and physical properties. It is used in vital castings. Since the manganese-silicon-chromium-vanadium steel maintains its high ductility at low temperatures, it is recommended for cast parts in service in the north.

Chromium-nickel-molybdenum steel has good hardenability and physical properties. It is distinguished by its resistance to wear and creep. This steel is used in special-purpose large and complex vital castings subject to heavy, variable loads at high temperatures (over 400 degrees centigrade).

3. Nickel-Chromium-Manganese-Molybdenum Steel

This steel possesses good hardenability and a high resistance to wear and creep. The chemical composition is as follows: carbon, 0.30-0.40 percent; manganese, 1.25-1.60 percent; nickel, 1.0-1.3 percent; chromium, 0.60-0.75 percent; and molybdenum, 0.3-0.5 percent.

The steel is used for vital, complex large castings subject to wear.

Multicomponent Steels

Steel Grade	Chemical Composition (%)						
	C	Mn	Si	Cr	Ni	Mo	V
40GKhL	0.37	1.49	0.46	0.52	--	--	--
40GKhL	0.39	1.38	0.57	0.63	--	--	--
30KhGSL	0.38-0.38 [sic]	0.90-1.20	0.50-0.75	0.50-0.80	--	--	--
40KhGSL	0.42	1.45	0.80	0.38	--	--	0.20
30GKhML	0.34	1.20	--	0.96	--	0.34	--
30N2KhML	0.30-0.35	0.50-0.10	--	0.60-0.90	1.75-2.25	0.15-0.25	--

Heat-Resistant, Stainless, and Wear-Resistant Steels

1. Heat-Resistant and Stainless Steels

It is necessary that a distinction be made between heat-resistant and heat-proof steels. Heat resistance is the ability of a steel to resist the formation of scale, whereas "heat-proof" is the term applied to the ability of steel to maintain its strength at high temperatures. Heat-proof steels are not considered in this handbook.

Castings of low-alloy and medium-alloy carbon steels used in the shipbuilding and especially in the machine building industries sometimes lack sufficient corrosion resistance against the action of humid air, superheated steam, acids, bases, flue gas, and high temperatures. At high temperatures these steels lose their strength and begin to creep. Low and medium alloy carbon steels do not bear high-temperature (400-600 degrees centigrade and over) water and steam pressures well. Some grades of steel, when kept at high but subcritical temperatures over long periods of time, precipitate graphite and lose their ductility and initial good physical properties.

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The corrosive process is the gradual, progressive destruction of the metal by the surrounding medium through chemical or electrochemical reactions.

Corrosion resistance is achieved either by the prevention of corrosion or by the formation of a thin, dense passivating film on the metal surface through the action of the medium upon the metal.

Highly heat-resistant, stainless, and acid-resistant steels must be of a monophase structure: ferritic, martensitic, austenitic, or ledeburitic.

The production of steels with high corrosion resistance is attained by alloying them with elements more noble than iron, such as copper, nickel, and molybdenum, or with easily passivated elements, such as chromium, silicon, and aluminum. The most widely used alloying element in heat-resistant and stainless steels is chromium. Chromium forms the best, densest, and strongest hermetic seal with metal. Small amounts of aluminum and silicon oxide improve the chromium oxide film but somewhat decrease its air tightness.

It has been established that the higher the temperature of the aggressive medium, the higher must be the chromium content in the steel, regardless of the nickel content. Nickel increases the density and bonding strength of the protective film in heat-resistant steels. It also increases the air tightness of the film and improves the physical properties of the steel. To have satisfactory corrosion resistance in humid air, steel must have a minimum chromium content of about 12 percent.

The carbon content of high-chromium steel has a great effect on electrochemical corrosion but no practical effect on chemical corrosion. And the greater the carbon content in high chromium steel, the less its resistance to electrochemical corrosion.

Besides the composition and structure of the steel, the cleanliness of the surface of the casting and the continuity of the casting skin have an essential effect upon corrosive resistance. A clean or polished surface and a continuous casting skin assure the cast part optimum corrosion resistance.

High-chromium stainless and heat-resistant steels may be divided into five groups: ferritic, semiferritic, martensitic, ferritic-carbidic, and ledeburitic.

Ferritic high-chromium steels with a content of up to 0.08 percent carbon and 13-14 percent chromium, and 0.08-0.12 percent carbon and 16-20 percent chromium, are used for cast parts operating at temperatures of 800-825 and 850-900 degrees centigrade, respectively.

Martensitic alloy chromium steels with a carbon content of 0.10-0.25 percent carbon, 13-15 percent chromium, and 2 percent nickel, and 0.15-0.20 percent carbon, 16-20 percent chromium, and 2 percent nickel, are used for cast parts operating at temperatures of 825 and 900 degrees centigrade, respectively. Martensitic stainless steels have entirely satisfactory corrosion resistance and are used for casting hydroturbine blades, fittings, pump parts, etc.

Ledeburitic high-alloy chromium heat-resistant steels are used in castings subject to high temperatures (1,050-1,100 degrees centigrade).

GOST 2176-43 applies to shaped corrosion and heat-resistant castings from high chromium steel which are subject to service in superheated steam, nitric or organic acids, ammonia gas, or acid and salt solutions at temperatures up to 1,100 degrees centigrade. The chemical compositions of high-chromium steels, in accordance with GOST 2176-43, are listed below.

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Steel Grade	Chemical Composition (%) C	Cr	Si	Mn	P (max)	S (max)
Kh28	0.5-1.0	26-30	0.5-1.3	0.5-0.8	0.1	0.08-0.10
Kh34	1.5-2.2	32-36	1.3-1.7	0.5-0.8	0.1	--

Note: If castings are subject to wear it is recommended that chromium content be decreased and carbon content be increased.

The chemical composition and application of heat-resistant, stainless, and acid-resistant steels used in various branches of industry are listed below.

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Steel Grade	Chemical Composition (%)									Uses
	C	Mn	Si	Cr	Mo	Ni	N	S	P	
30ML	0.26-0.35	0.50-0.80	0.25-0.45	0.25	0.30	0.30		0.050	0.050	Turbine parts operating at temperatures of 400-500°C
25Kh14L	0.22-0.28	0.30-0.60	0.50-0.70	12.00-14.00		0.60		0.030	0.030	Hydroturbine blades
Kh18N8L	0.25-0.40	0.40-0.60	0.80-1.20	18.00-20.00		7.50-8.50		0.040	0.050	Acid-resistant castings
Kh25N2L	0.40-0.60	0.40-0.70	1.00-2.00	24.00-26.00		1.50-2.00		0.040	0.040	Hearth plates, pots, other parts operating at temperatures of 1,100°C and subject to impact loads
Kh25N12L	0.40-0.55	0.20-0.50	0.70-1.50	24.00-27.00		12.00-13.50		0.030	0.035	Crucibles, bottom plates, other parts operating at temperatures up to 1,000°C
Kh25N20L	0.40-0.60	0.40-0.70	1.50-2.00	24.00-26.00		19.00-26.00		0.040	0.040	Hearth plates, bottom plates, boxes, other parts operating at temperatures of about 1,000°C and subject to impact loads
Kh25N2S1.5L	0.10-0.23	0.30-0.60	1.20-1.80	26.00-29.00		1.80-2.40	up to 0.2	0.030	0.030	Parts operating in an atmosphere of illuminating gas, SO_3, furnace gas, H_2S, or a temperature of 1,200°C
Kh27N2S2L	0.25-0.40	0.30-0.60	1.40-2.20	26.00-29.00		1.80-2.40	0.20-0.30	0.030	0.030	Parts operating under the same conditions (above) but at temperatures of up to 1,100°C

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It is known that some ship parts (screw propellers, pumps, etc.) operating in water are destroyed by corrosion and physical action (cavitation). Cavitation generally occurs at defective spots on the surface of the casting or at stress raisers. The best cavitation-resisting castings are made of 25Kh14L and Kh18N8L steel.

2. Wear-Resistant Steels

The most widely used wear-resistant steel is Gadfil'd steel (G14L). This steel has the greatest wear resistance of all existing wear-resistant steels. Gadfil'd steel is austenitic in structure, and therefore nonmagnetic.

The optimum chemical composition of G14L steel used for shaped castings is as follows: carbon, 1.3 percent; silicon, 0.75 percent; manganese, 12.5 percent; phosphorus, not over 0.10 percent; and sulfur, up to 0.02 percent. The high phosphorus content in G14L steel has practically no effect on its plasticity since the phosphorus is in a solid solution of austenite and is not precipitated as phosphide along the granular boundaries, as is the case in ordinary steels.

Despite their low hardness, castings from G14L steel are practically unmachineable by high-speed steels and only poorly machineable by Pobedit tools.

The high strength, plasticity, and wear-resistance, as well as the poor machineability of G14L steel is due to the breakdown of the austenite and the formation of secondary structures as a result of the cold hardening. Therefore, G14L steel has very high wear resistance only when undergoing cold hardening during service.

In casting complex or thick-walled (over 100 millimeters) parts of this steel, either a lesser carbon content should be used (below 1.0 percent) or the steel should be alloyed with additional nickel or carbide-forming elements. Supplementary alloying of this steel with 1.0-1.5 percent aluminum for parts with wall thicknesses of 80-120 millimeters, and 3-5 percent aluminum for parts with large wall thicknesses, will assure a uniform austenitic structure in the castings.

Other highly wear-resistant, high-alloy chromium steels worthy of mention have the following composition: carbide steel -- carbon 0.4 percent, chromium, 23 percent, and nickel, 0.6 percent; and martensite steel -- carbon 0.6 percent and chromium 16.5 percent.

Graphitized Steel

Common gray and nodular cast irons possess considerably better casting properties, resiliency, and stress-raiser-induced fracture indices than steel. Steel, on the other hand, has greater strength and plasticity. And graphitized steel comes closest to combining both the advantageous properties of cast irons and steel.

In strength and applicability, cast graphitized steel is similar to the rolled 45 and 45G2 grade steels. Therefore, many parts made of forgings may be replaced with castings of graphitized steel.

The EI293, EI336, and EI366 grades of graphitized casting steel are used in industry. The EI293 steel is widely used in preparing stamps for cold stamping whose stability is about ten times that of stamps made of the U10 and U12 steels and about double that of those made of the Kh12M steel. The EI366 steel has good wear resistance and is used in facing plates for shot-blasting grinders, housings, and vanes, tracks, sand-blasting nozzles, worm-gear crowns, machine parts as well as other assemblies subject to abrasive wear. Graphitized

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steel is fully suitable for casting small tractor type crankshafts, chill molds, stamps, grates, etc. Cast stamps from graphitized steels are equal in stability with forged stamps but require greater technology in manufacture and are considerably less expensive.

Graphitized steel of the following composition is used in the USSR: carbon, 1.5 percent; silicon, 0.85-0.95 percent; manganese, 0.4 percent; sulfur and phosphorus, 0.03 percent each. When casting large, complex parts, up to 0.25 percent molybdenum is added and the silicon content is reduced by up to 0.8 percent to increase hardenability.

On the basis of the latest research, the following graphitized steel may be recommended for casting: carbon, 1.2-1.4 percent; manganese, 0.6-0.9 percent; silicon, 0.7-1.10 percent; sulfur and phosphorus, not over 0.05 percent each; nickel, up to 0.5 percent; chromium, up to 0.35 percent; and copper, 0.4-0.7 percent.

There is no difference in the smelting of graphitized and high-carbon steels. It may be smelted in basic as well as acid arc or induction electric furnaces. To increase plasticity it is recommended that the graphitized steel be modified with microadditions of ferroboron (0.04-0.07 percent), silicocalcium, or magnesium (0.2-0.3 percent). The strength may be increased by additions of aluminum (0.2-0.3 percent), ferrosilicon (0.1-0.2 percent), or silicozirconium (0.15-0.20 percent). Admixtures are made into the ladle at temperatures of 1,575-1,625 degrees centigrade.

The machinability of graphitized casting steel is entirely satisfactory.

Selection of Steel Grade for Shaped Casting

The great variety of steel grades suitable for casting places at the disposal of the designer a great many resources. The principal bases for selection are generally the stress and strength limits. There are other considerations, however. The designer must consider the technology of the material.

By "technology" is meant the suitability of the material for pouring, heat treatment, and machining, and its weight, reliability, and cost.

It is possible to compare the cost of various castings by comparing weights and average wall thicknesses. If the casting cost for ordinary cast iron is taken as 1.00, then the cost of other equiweight castings, assuming the same casting labor, would be:

Gray iron	1.00
Nodular iron	1.05
Malleable iron	1.40
Unannealed carbon steel	1.90
Annealed or normalized steel	2.20
Low-alloy heat-treated steel	2.70
Manganese high-alloy steel	2.80
Chromium-nickel-molybdenum steel	3.50
High-alloy chromium-nickel steel, grade Kh18N8L	4.20

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Machine parts made of high-temper, hardened and annealed chromium-nickel steel, which are subject to wear, last three to four times longer than the same parts made of annealed carbon steel.

It has been established that many parts made of nodular iron which are subject to wear are better than steel.

For castings with sudden transitions from thick to thin walls but with small shrinkage, steels with a low carbon content are recommended.

For noncomplex castings with wall thicknesses of over 15 millimeters, low carbon or medium carbon steels are recommended. For thin-walled castings (5-15 millimeters), high-carbon steels are preferred.

In selecting the grades of carbon steel on the basis of carbon content, the following additional factors must be considered.

Steels with a higher carbon content are needed for parts subject to wear. The greater the weight of the casting, the lower should be the carbon content. The greater the cross-section of the casting, the greater its internal stresses from temperature fluctuations, the greater must be the heat conductance of the steel, and, therefore, the lower must be the carbon content. Castings of average strength and quality and relatively low weight may be successfully made of Bessemer steel.

Machine parts which must have a tensile strength of over 50 kilograms per square millimeter, a yield strength of over 40 kilograms per square millimeter, and an elongation of over 30 percent, must be made of alloy steels, such as grades 37KhNL, KhN2L, 30NML, 30KhML, 40GSKhFL, etc.

Parts subject to great abrasion should be made of manganese-grade steels 25GL, 40GL, 50G2L, or 90G14L.

In selecting alloy steels for heavy, highly loaded parts, the hardenability of the steel must always be considered. The 40GSKhFL grade steel is suitable for such purposes.

Parts operating at temperatures over 400 degrees centigrade should, as a rule, be made of steel grades 35Kh2GML, 35Kh5GML, 30NML, etc. Parts operating at temperatures down to 75 degrees below zero centigrade are best cast of alloy nickel and vanadium steels. For lower temperatures, high-alloy austenitic or ferritic steels with a very low carbon content should be used.

To make the best possible use of a steel, the designer should first become familiar with all the properties of the steel.

To get castings that are stronger and have improved properties, steels have lately been modified with microadmixtures of magnesium, calcium, cerium, etc.

II. PROPERTIES OF IRON CASTINGS

Castings From Gray and Nodular Iron

The term "gray iron casting" is applied to specimens whose microsections contain graphite and are free of structurally free cementite or ledeburite. A fresh fracture of such a casting would be light or dark gray in color. Cast iron which does not contain special admixtures is known as common cast iron. If alloying elements such as chromium, nickel, copper, molybdenum, etc., are added the iron is termed "alloyed" or "special" cast iron.

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Blast furnace iron, smelted from Khalilovsk or Yelizavetinsk ores containing chromium and nickel, is known as naturally alloyed cast iron, as distinguished from the cast iron to which special alloys have to be added with the steel scrap or in the form of shavings or ferroalloys.

The cost of naturally alloyed iron castings is less than that of castings from iron to which expensive ferroalloys have to be added. However, naturally alloyed iron castings are more expensive than common iron castings.

When steel constitutes over 20 percent of the charge, the resultant cast iron is known as steely pig iron; a more accurate title would be "cast iron with decreased carbon content." Cast iron of any chemical composition or structure, which is treated in the ladle, trough, or pouring basin with small admixtures of modifiers, is known as nodular (modified) iron.

Modification is generally accompanied by grain refinement, more spherical graphite, and, sometimes, oxidation, which naturally results in improved mechanical and physical properties.

Current research indicates the superiority of cast iron over steel in castings subject to cyclic, alternating loads.

At present, nodular irons are used by many plants of the Ministry of Maritime and River Fleet USSR.

All iron castings used aboard ship may be divided into the following groups, in accordance with GOST 1412-48, the Maritime Register of the USSR, 1952, and other sources.

Group	Cast Iron Grade (GOST 1412-48)	Application	Specific Parts
A	SCh 12-28 or SCh 18-36	Nonvital parts	Ballast, deck plates, hydraulic columns, oil stuffing boxes and pump heads, large forgings, nonvital gears, bearing caps, flywheels, reducer caps, etc.
B	SCh 21-40 or SCh 24-44	Vital parts subject to vibration and variable loads without impacts, operating at temperatures below 300°C	Steam-engine mounts, pedestals, frame bearings, auxiliary machine and camshaft bearings, level cantilevers and supports, flywheels, pulleys, regulator housings, condensor caps, steam-engine cylinders, steam superheater parts; steam fittings, piston rings, hydraulic pump housings, electric-motor housings, metal-cutting machine parts, etc.
C	SCh 24-44 (*1) or MSCh 28-48	Vital parts subject to large but latent loads; parts subject to temperatures not over 400°C; parts subject to pressures of 5-10 atmospheres	Steam-engine cylinders; steam superheater parts; engine cylinder blocks; compressor and oil pump cylinders; housings and heads of oil and scavenger pumps; bilge, circulating, and feed pump housings; steam-engine bushings and pistons; steam-engine bearing cases and caps; steam-engine piston rings; water shutter housings; tees; worm-gear crowns; hydraulic press plungers; housings and caps of

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Group	Cast Iron Grade (GOST 1412-48)	Application	Specific Parts
			vital reducers; gears; bushings; small valves; pipe caps and unions with gas/liquid pressures under 10 atmospheres; boiler and engine steam fittings; gate valves and gage valve bushings; inlet, exhaust, and starting valve housings; seats and inset rings; oil filter housings; sprayer housings; exhaust valve discs; etc.
D	MSCh 28-48 (*2) or MSCh 32-52	Especially vital parts subject to large but latent loads and wear; parts not subject to over 400°C	Jaw washers; cam and crankshaft gears; bushings, pistons, and piston rings for compressor engines and oil and scavenger pumps; high-pressure compressor cylinders; engine gear drives; high-speed engine frames; large-bridge crane gears; large pulleys and flywheels; bending stamps for friction and hydraulic presses; other vital parts
E (*4)	MSCh 32-52 (*3) or MSCh 35-56	Parts subject to great wear, alternating tensile and compressive but no impact stress; parts subject to liquid or gas pressure not over 20 atmospheres	Hawses, hawse pipes, cleats, chocks, helical gears for freight hoists, windlass star wheels, deadwood pipes, air hammer and forge press cylinders and housings, injector housings, chain drive sprockets, other vital parts
F	MSCh 35-56 or MSCh 38-60	Parts subject to temperatures up to 600°C and liquid and gas pressures not over 25 atmospheres	Furnace frames, baffles and reverberatory plates, gas-steam-water line parts, noiseless reducer gears, crusher balls, etc,

(*1) Wall thickness of these castings must not be below 8 millimeters.

(*2) Wall thickness of these castings must not be below 10 millimeters.

(*3) Wall thickness of these castings must not be below 20 millimeters.

(*4) It is recommended that alloyed cast irons with up to 0.6 percent chromium and 1.2 percent nickel be used in group E castings.

The chemical composition of both common and nodular gray iron must be regulated on the basis of wall thickness and microstructure.

At a high cooling rate, brittle, hard, structurally free cementite is separated from cast iron, thus decreasing its machineability. Experiments indicate that gray iron is more sensitive to cooling rate variations than nodular iron.

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Nodular gray iron has considerable advantages over common gray iron as a structural material. It is denser and more homogeneous. Nodular gray iron has greater vibration damping power than does carbon steel.

Alloy Cast Iron

The three elements having the greatest effect on the hardness increase of cast iron are vanadium, molybdenum, and chromium. Copper, manganese, and nickel increase hardness only insignificantly.

Chromium and nickel are the alloying elements having the greatest use and recognition in the USSR; they are introduced into the charge in the form of naturally alloyed iron.

The use of naturally alloyed irons for castings with increased strength and hardness is entirely feasible. The builder has the authority to specify grades of nodular gray irons in accordance with GOST 1412-48, citing the necessity of their being alloyed with chromium and nickel.

Chromium-nickel nodular iron is recommended for vital group E and F parts.

Spheroidal Graphite Cast Iron

Scientific-research studies of recent years have changed the conception of cast iron as a structural material with comparatively low strength and especially low plasticity. The strength and plasticity of cast iron is dependent upon the structure of the metallic base and the quantity, form, and character of the graphite inclusions in the mother metal. In common gray and nodular irons the graphite inclusions are in the form of large, medium, or small size plates. Such a graphitic form causes considerable concentrations of stress when loads are applied to cast parts, resulting in a considerable decrease of strength and plasticity. Spheroidal graphitic inclusions considerably decrease the concentration of stress. Therefore, with an optimum structure of the metallic base, the strength and plasticity of cast iron equals that of steel.

With spheroidal graphitic inclusions the ratio between surface and volume is at a minimum. It is possible to get a varying metallic base in cast iron with spheroidal graphite: pearlitic, pearlitic-ferritic, ferritic-pearlitic, ferritic, martensitic, or austenitic (the latter two in case of alloying or heat treatment).

The congruence of low cost and good physical and technological properties assures wide application for spheroidal graphite cast iron. The builder has the opportunity of cutting machine and other costs by replacing steel castings and forgings with cast iron. Moreover, a wide perspective is also opened for decreasing weight.

The principal impediment to the introduction of spheroidal graphite cast iron parts into industry is the absence of an adequate method of introducing magnesium into the liquid cast iron. Existing methods of adding magnesium to liquid cast iron have many disadvantages.

To increase the effectiveness of the magnesium absorption many plants use special magnesium alloys. The compositions of the most important of these alloys are listed in the following table.

The replacement of magnesium with magnesium alloys in modifying cast iron assures a smoother reaction and eliminates boiling over in the ladle.

Raw Materials for Smelting Alloys	Alloy Composition (%)						Amount of Alloy Added (%)		Method of Adding Alloy to Liquid Cast Iron	Recommended by
	Mg	Si	Ca	Cu	Ni	Fe	Per Weight of Material	Converted to Mg		
Mg&75%FeSi	15-25	56-64	--	--	--	Remainder	2.4	0.35-0.50	Alloy is poured into cylindrical measuring containers with iron rod inserts which are then used as handles for charging into the ladle	State Trust for Organization of Production in Automotive Industry
Mg&75%FeSi	20-25	55-60	--	--	--	Remainder	1.5-2.0	0.25-0.75	Under bell directly into ladle with special cap	Maritime and River Fleet Ministry plants
Mg&Cu	7-50	--	--	93-50	--	--	3.5	0.50-1.00	In special chamber with aid of bell	Central Scientific-Research Institute of Technology and Machine Building
Mg&Ni	7-50	--	--	--	93-50	--	--	--		
Mg&Ni	20	--	--	--	80	--	--	0.20-0.25	On red hot ladle floor without chamber or cap	Grechin
Mg&75%FeSi	6-8	50-60	--	--	--	Remainder	2.0	0.15-0.25	Under bell directly into lable without cap	Sumsk Plant
Mg&75%FeSi	3-5	50-60	--	--	--	Remainder	2.0	0.15	Under bell directly into ladle without cap	Scientific-Research Institute of Chemical and Machine Building Ushakov
Mg&45%FeSi&SiCa	12	SiCa 53 FeSi 45	--	--	--	--	--	0.30	Under bell directly into ladle without cap	Scientific-Research Institute of Chemical and Machine Building Ushakov
Mg&Cu&SiCa	12	Remainder	SiCa 20	--	--	--	--	0.30	Under bell directly into ladle without cap	Scientific-Research Institute of Chemical and Machine Building Ushakov

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In accordance with the classifications of the Central Scientific-Research Institute of Technology and Machine Building, spheroidal graphite cast iron is divided into two types. The first type is cast iron with a pearlitic or a pearlitic-ferritic base (ferrite content of up to 20 percent). The second type is cast iron with a ferritic-pearlitic (pearlite content of up to 15 percent) or a ferritic structure. The first type of cast iron, codified as SPChP, is divided into 2 grades: SPChP45 and SPChP55 (superhard pearlitic cast iron; the term "superhard" is dialectically incorrect but cannot be abolished until a GOST is ratified). The digits indicate the minimum standard tensile strength in kilograms per square millimeter.

The chemical composition of the basic liquid cast iron is controlled so that its castings (without magnesium admixtures) would have a gray fracture. Depending upon the grade and structure of the casting, the chemical composition of the initial liquid cast iron should lie within the following range:

	(Percent)
Carbon	2.50-3.70
Silicon	0.80-3.00
Manganese	0.40-0.80
Phosphorus	0.08-0.20
Sulfur	up to 0.14

Spheroidal graphite cast iron may also be produced with a higher carbon content but this is recommended only in small-section castings. The larger the section of the casting, the lower should be the carbon content in the initial iron. If large section parts are cast of high-carbon cast iron, the strength of the iron is decreased due to the formation of not only spheroidal but lamellar graphite in the larger sections. The silicon content of cast iron is determined by the greatest wall thickness of the casting and the desired structure of the mother metal (pearlitic, pearlitic-ferritic, ferritic-pearlit, ferritic). For castings with identical wall thicknesses, the silicon content of spheroidal graphite cast iron can be somewhat greater than that of gray iron. To prevent blanching in casting thin-walled parts, it is necessary to admix ferrosilicon into the ladle in such quantity as to assure a silicon content increase of 0.3-0.4 percent. If a magnesium-silicon alloy is added to the liquid cast iron, then that silicon should also be taken into account.

Manganese has a very great effect on the strength and plasticity of spheroidal graphite cast iron.

The effect of manganese as an alloying element in smelting spheroidal graphite cast iron is more pronounced than in common gray iron in which manganese and sulfur form the compound MnS, thus neutralizing the harmful effect of the sulfur. In the smelting of spheroidal graphite cast iron, magnesium serves as the sulfur neutralizer. Therefore, it is recommended that the manganese content be kept with 0.5-0.8 percent in cast irons with a pearlitic base. In ferritic base cast irons, however, the manganese content should not exceed 0.4 percent, to avoid decreasing plasticity. A phosphorus content up to 0.5 percent does not deter the formation of spheroidal graphite cast iron but considerably decreases its plasticity. Thus, the phosphorus content is limited to 0.1 percent in SPChP class B cast irons, to 0.2 percent in class A irons, and to 0.1 percent in SPChF-type cast irons.

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The standards of the Central Scientific-Research Institute of Technology and Machine Building for the production of SPChP45 cast iron are given in the following table:

Wall Thickness

75-150 mm

Chemical Composition of Initial Cast Iron (%)

C	Si	Mn	S	P
3.2 and over	2.0-2.5	0.5-0.8	up to 0.14	Class A, up to 0.2 Class B, up to 0.1

Chemical Composition of Cast Iron After Admixtures were Added (%)

Si	S	Mg
2.0-2.5	0.03	0.05-0.12

Proportion of Admixtures to Weight of Liquid Metal

Mg	FeSi
0.50-0.75	Admixture not required

Note: (1) Admixture is ferrosilicon of 0.3-0.5 percent is required only when wall thickness is under 75 millimeters or when weight of casting is low (about 100 kilograms).

(2) Magnesium proportion listed is for pure magnesium or high-magnesium-content alloy when added with closed-bottom bell.

The data supplied by this institute for the smelting of SPChP55 cast iron are as follows:

Wall Thickness (mm)	Chemical Composition of Initial Cast Iron (%)				
	C	Si	Mn	S	P
up to 10	3.4 and over	2.4-2.7	0.5-0.8		
10-30	3.2 and over	2.2-2.5	0.5-0.8	0.14 0.14	Class A, up to 0.20
30-75	3.0 and over	1.8-2.1	0.5-0.8		
70-150	2.7-3.1	0.8-1.2	0.5-0.8	0.14 0.14	Class B, up to 0.10

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Wall Thickness (mm)	Chemical Composition of Cast Iron After Admixtures Were Added (%)			Proportion of Admixtures to Weight of Liquid Cast Iron (%)	
	Si	S (max)	Mg (max)	Mg	FeSi
up to 10	2.7-3.0	0.03	0.05-0.10	0.25-0.35	0.8-1.0
10-30	2.5-2.8	0.03	0.05-0.10	0.25-0.35	0.6-0.8
30-75	2.1-2.4	0.03	0.05-0.10	0.35-0.50	0.5-0.7
75-150	1.4-1.6	0.03	0.05-0.10	0.50-0.70	0.5-0.8

Note: (1) In casting parts with a wall thickness of 76-150 millimeters, 20 percent and more of steel is added to the charge. (2) The upper magnesium content and lower silicon content limits are used for parts in which the predominant wall thickness is near the maximum wall thickness. (3) The manganese content should be at the lower limit if high plasticity is desired.

The data supplied by the above institute for the smelting of SMPF-5 cast iron are as follows:

Wall Thickness (mm)	Chemical Composition of Initial Cast Iron (%)				
	C	Si	Mn	S	P
up to 10	3.4 and over	2.6-3.1	0.4	0.14	0.10
10-30	3.4 and over	2.4-2.8	0.6	0.14	0.10
30-75	3.2 and over	2.2-2.6	0.6	0.14	0.10
75-150	3.0 and over	2.2-2.6	0.6	0.14	0.10

Wall Thickness (mm)	Chemical Composition of Cast Iron After Admixtures Were Added (%)			Proportion of Admixtures to Weight of Liquid Cast Iron (%)	
	Si	S (max)	Mg	Mg	FeSi
up to 10	3.0-3.2	0.03	0.05-0.10	0.26-0.35	0.7-0.9
10-30	2.8-3.2	0.03	0.05-0.10	0.35-0.50	0.7-0.9
30-75	2.6-3.0	0.03	0.05-0.10	0.50-0.70	0.7-0.9
75-150	2.4-2.8	0.03	0.05-0.10	0.50-0.70	0.6-0.8

SPChF10-grade cast iron is produced by heat-treating castings of SPChP55 Class B cast iron.

The uses to which spheroidal graphite cast iron may be put have been insufficiently studied. In shipbuilding plants this metal may be used for casting crankshafts for technical and roadstead fleets, screw propellers (except for long-range and ice navigation ships), cylinder bushings, pistons, valves, fittings and valves subject to pressure, housings, scavenger pump connecting rods, low-pressure turbine cylinders, diaphragms, bushings for chassis and impact bearings, shaft casings, windlass and hoist gears, oil-pump housings, intermediate shaft couplings (except for long-range and ice navigation ships), chain drum sprockets for windlasses, etc.

Spheroidal graphite cast iron has satisfactory weldability and may be cut with an oxyacetylene torch.

White Cast Iron

White iron castings are widely used in coal mills, various crushers, sand and shot blasters, railroad wheels, etc.

The wearability of white iron castings is several times that of gray iron but is somewhat less than that of austenitic manganese steel (G14L). White iron is usually cast in chills. Because of the varying speeds of crystallization, white iron castings have a sharply pronounced lack of homogeneity. K. P. Bunin [a Soviet metallurgist] has indicated that the optimum chemical composition of machine parts subject to great wear is cast iron with up to 3.5 percent carbon, 0.7-0.8 percent silicon, and up to 3.0 percent manganese, with a minimum phosphorus and sulfur content. For parts subject to alternating temperatures it is recommended that 0.2-0.5 percent molybdenum or nickel and up to 0.6 percent chromium be added.

Molybdenum decreases the tendency of castings toward transcrystallization and refines the initial structure of the cast iron, thus increasing its strength. M. M. Dobrotvorskiy has shown experimentally that the treatment of liquid cast iron with magnesium or tellurium considerably decreases the depth of the white iron zone while sharply increasing its strength.

Malleable Cast Iron

White cast iron, when subject to a long anneal (malleableizing) becomes malleable cast iron. The name malleable [of which the literal meaning in Russian is forging] is a misnomer since this iron cannot be forged. There are two types of malleable cast iron, depending upon method of production: blackheart and whiteheart. The annealing of white iron castings (to attain blackheart iron) is done in a neutral or weak acid atmosphere. This treatment dissociates the cementite. The annealing of white iron (to attain whiteheart iron) is done in an acid atmosphere. In this process the iron is decarburized.

In the production of whiteheart malleable cast iron, two simultaneous reactions occur: decarburization and cementite dissociation. However, the decarburization is the more important since additional ore is required to anneal the castings. Experimental analyses have shown that the decarburization process occurs in conjunction with the formation of a gaseous phase in which the oxygen of the ore combines with the carbon in the casting as follows:

$$FeO + CO = Fe + CO_2,$$

$$C + CO_2 = 2CO.$$

The chemical composition of a malleable iron casting is not uniform throughout the cross section. In the outer layer the carbon content fluctuates from 0.2 to 0.5 percent while the carbon content of the core is from 0.5 to 0.9 percent.

Pearlitic malleable cast iron is a comparatively recent structural material and is used when high strength and wearability are required.

The chemical composition of malleable cast iron both before and after annealing is as follows:

Element	Whiteheart Malleable Cast Iron		Blackheart Ferritic Malleable Cast Iron		Blackheart Pearlitic Malleable Cast Iron	
	Preanneal	Postanneal	Preanneal	Postanneal	Preanneal	Postanneal
C_{total}	2.90-3.30	0.40-2.00	2.20-2.80	1.70-2.70	2.20-2.80	1.70-2.70
$C_{graphitic}$	--	0.20-1.50	--	1.60-2.80	--	0.90-2.20
$C_{combined}$	2.90-3.30	0.30-0.70	2.20-2.80	0.10-0.20	2.20-2.80	0.50-0.80
Si	1.00-0.60	1.00-0.60	1.50-0.80	1.50-0.80	1.50-0.80	1.50-0.80
Mn	0.40-0.60	0.40-0.60	0.30-0.50	0.30-0.50	0.30-1.00	0.30-1.00
P	up to 0.2	up to 0.2	up to 0.2	up to 0.2	up to 0.2	up to 0.2
S	0.12-0.20	0.12-0.20	0.05-0.15	0.05-0.15	0.05-0.15	0.05-0.15

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It is apparent that the carbon content in whiteheart malleable iron is greater before annealing and less after annealing than in blackheart malleable iron. Therefore, the annealing time of whiteheart malleable iron is greater than that of blackheart iron. Wall thickness is one of the basic factors determining annealing time. In large castings the carbon combustion or cementite dissociation process is not completed even during lengthy anneals. Consequently, a wall-thickness limit must be set to prevent low-strength cast iron.

The wall thickness of whiteheart malleable iron castings fluctuates from 3 to 15 millimeters, but may be as high as 50 millimeters in blackheart castings.

The following table lists the typical applications of malleable cast iron (based upon the Maritime Register, 1952, and other sources).

Group	Grade of Malleable Cast Iron	Application	Specific Parts
A	KCh40-3 or KCh32-12	Boiler or ship lines	Water fittings; water compartments for boilers; water-line joints; couplings; tees; crosspipes; other fittings for oil, air, or steam lines with steam temperatures of up to 200°C and rated pressures of 20 kg/cu m; valves; spigots; pipe fittings.
B	KCh35-4 or KCh35-10	Hull parts and ship fittings	Illuminators, thwart angle irons; deck hooks; row locks; row lock planks
C	KCh30-6 or KCh30-3	Cabin fittings and hardware	Door assemblies, lock parts, door keys, hooks, hangers, angle brackets, handles, other nonvital parts.

Antifriction Cast Iron

Antifriction cast iron has lately found use in friction points as a substitute for deficient nonferrous bearing alloys.

The wearability of antifriction cast iron is determined by its structure: the more pearlite and the less ferrite, the greater the wearability. Cast iron with a stable pearlitic structure is produced by adding naturally alloyed cast irons to the charge.

Antifriction grades SChTsI and SChTsII cast irons are used only under conditions of latent specific load. For service under more extreme conditions, a titanium-copper antifriction cast iron with up to 2.0 percent copper and up to 1.2 percent titanium is recommended.

The chemical composition of castings from antifriction gray iron (in accordance with GOST 1585-12 [sic]) is as follows:

Cast Iron Grade	Chemical Composition (%) C	Si	Mn	P	S (max)	Cr	Ni	Cu	Al
SChTs	3.2-3.6	2.2-2.4	0.6-0.9	0.15-0.25	0.12	0.20-0.35	0.3-0.4	0.2-0.3	0.10-0.15
SChTSII	3.2-3.6	2.2-2.4	0.6-0.9	0.15-0.25	0.12	0.20-0.35	0.3-0.4	0.2-0.3	--

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Note: Silicon content may vary depending on wall thickness so long as structure remains pearlitic.

Titanium-copper alloy may be subject to friction with latent specific stress up to P·V = 75 kilograms per square centimeter and a speed of 3.0 meters per second.

Heat-Resistant Cast Iron

Special alloyed heat-resistant cast irons are used in parts subject to high temperatures. Heat-resistant and alloyed cast irons generally are divided into three classes: low alloy, medium alloy, and high alloy. Cast iron of the following chemical composition is used at plants under the Ministry of Maritime and River Fleet USSR for making fire-grate bars: carbon 3.2-3.3 percent, silicon 1.4-1.6 percent, manganese 0.4-0.6 percent, chromium 0.6-1.0 percent, nickel 0.25-0.30 percent, titanium up to 0.12 percent, phosphorus up to 0.25 percent, and sulfur up to 0.08 percent.

This cast iron is smelted with an addition of 34-40 percent naturally alloyed cast iron and 20-25 percent steel to the charge. The above iron is recommended for diesel engine parts and cold-bending stamps.

Medium-alloy heat-resistant cast irons contain 2.0-4.0 percent silicon, up to 1.5 percent chromium, up to 0.6 percent manganese, and 3.0-3.3 percent carbon. Such iron is recommended for cold-bending stamps.

High-alloy cast irons (nickel-copper-chromium, nickel-silicon-chromium) are austenitic. The former has high corrosive resistance, the latter, high heat resistance.

Nickel-copper-chromium cast iron has good resistance to sulfuric and acetic acid and sea water, but has poor resistance against nitric acid. The structure of this cast iron is austenitic, graphitic, and chromium carbidic. The quantity of carbides increases with the chromium content; the machineability of the castings is simultaneously decreased. Nickel-copper-chromium cast iron also possesses high heat resistance in a gaseous medium (up to 850 degrees centigrade).

Nickel-copper-chromium cast iron has good weldability and may be used as welding rod in welding common or nodular iron castings.

Nickel-silicon-chromium cast iron has good heat resistance and may be used for casting furnace fittings subject to temperatures of about 950 degrees centigrade.

Aluminum cast iron such as "chugal'" has very high heat resistance. The chemical composition of this cast iron lies within the following range: carbon 1.2-2.0 percent, aluminum 20-24 percent, silicon 1.3-2.0 percent, manganese 0.6-0.8 percent, and sulfur 0.01-0.03 percent.

Aluminum cast iron may be recommended for casting furnace fittings subject to temperatures of 950 degrees centigrade.

The latest research of the Central Scientific-Research Institute of Technology and Machine Building indicates that chromium and silicon cast irons modified with magnesium, i.e., spheroidal graphite cast irons, have a very high heat resistance.

Chromium cast iron has the following composition: carbon, 3.0-3.1 percent; silicon, 2.5-3.0 percent; manganese, 0.5-0.7 percent; phosphorus, 0.1-0.15 percent; sulfur, not over 0.05 percent; and chromium, 2.5 percent. The iron is modified with 0.8 percent magnesium and 1.0 percent ferrosilicon.

Silicon cast iron modified with 0.9 percent magnesium and 1.0 percent ferrosilicon has the following composition: carbon, 2.3 percent; silicon, 7.0 percent; manganese, 1.5 percent; phosphorus, 0.14 percent; and sulfur, 0.02 percent. These cast irons are suitable for service at temperatures of 800-850 degrees centigrade.

III. SUBSTITUTES FOR CASTING BRONZES

The following table lists tin casting bronzes and the tin-free bronzes which may be substituted for them:

Tin Bronze	Adequate Tin-Free Bronze Substitute
BrOtsSN 3-7-5-1	BrAZh 9-4, BrAZhN 11-6-6, BrAZhMts 10-3-1.5
BrOtsS 6-6-3	BrAZh 9-4, BrAZhN 11-6-6
BrOtsS 5-5-5	BrA5, BrA7, BrKMts 3-1
BrOtsS 3-11-5	BrKMts 3-1, BrA5, BrA7
BrOtsS 4-4-1.7	BrA5, BrA7

IV. SUBSTITUTES FOR TIN BABBITTS

Babbitt substitutes may be divided into the following groups:

1. Copper-base nonferrous alloys -- lead bronzes, silicon, and silicon-lead brasses.

2. Zinc-base nonferrous alloys -- TsAM-type zinc-aluminum alloys.

3. Ferrous alloys -- antifriction and nodular cast irons and iron-graphite.

4. Plastics and wood-plastics -- textolite, texto-bakelite, lignofole, lignoston, etc.

Lead Bronze

Experiments indicate that bronzes with 27-33 percent lead possess very high antifriction properties. The BS30 bronze may be used at specific pressures of 250 kilograms per square centimeter and peripheral speeds of 8-20 meters per second. The physical properties of this bronze are maintained at high temperatures, which is not the case with B83 babbitt which loses its hardness at 100 degrees centigrade. This bronze is widely used as a substitute for tin babbitts at friction points. BS30 bronze bushings are used in aircraft engines, high-power turbines, internal-combustion engines, steam hoists, etc.

Silicon and Silicon-Lead Alloys

As a result of their good physical and antifriction properties, the LK80-3 and LKS80-3-3 brasses may be used as substitutes for tin babbitts. Their utilization is, however, limited for a number of reasons:

1. When poured into a steel bushing the brass does not adhere well and requires mechanical fastening.

2. A good bond between steel and brass is achieved by beading the brass onto the steel bushing; the beading itself, however, is a very difficult operation.

The use of brasses and bronzes as partial (about 25-30 percent) substitutes of tin babbitts has some advantages.

The combination of babbitt B16 and bronze may be used as a substitute for B83 babbitt in vital parts such as crank bearings in high-power steam engines, heavy-flywheel bearings, etc.

Zinc Base TsAM Type Alloys

These alloys primarily include the various TsAM-type zinc-aluminum alloys: TsAM 10-5, TsAM 20-10, TsAM 5-10, TsAM 5-13, etc. The TsAM 10-5 alloy has the best properties. Its composition is: aluminum, 9-11 percent; copper 4.5-5.5 percent; lead 0.03 percent; tin, 0.05 percent; cadmium, 0.015 percent; iron, 0.4 percent; total admixtures, 0.6 percent; zinc, remainder. The maximum stress to which this alloy may be subjected is as follows: specific pressure, 200 kilograms per square centimeter; and sliding speed, 8 meters per second. Because of its high physical and antifriction properties, the TsAM 10-5 alloy is used as a substitute for high-tin babbitts.

Ferrous Substitutes for Nonferrous Alloys

Ferrous metals -- malleable cast iron, antifriction iron, nodular cast iron -- may in some instances be used as substitutes for tin babbitts. But inasmuch as cast irons are brittle and cannot generally withstand severe service, such substitutions must be treated with due care. Nonferrous antifriction alloys are widely replaced with porous iron-graphite (a mechanical mixture of 96-98 percent iron and 2.4 percent graphite compressed at 4-6 tons per square centimeter pressure and sintered at 1,100 degrees centigrade in a controlled atmosphere).

The maximum physical stress to which these substitutes may be subjected are as follows:

Substitute	Maximum Specific Pressure, P (Kg/sq cm)	Maximum Sliding Speed, V (m/sec)	Maximum PV (kg/sq cm/sec)
High quality, antifriction cast iron, nodular cast iron, or malleable cast iron	up to 50	0.5-3.0	50-80
Iron-graphite	up to 60	up to 55	up to 125

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Plastics and Wood-Plastics

Textolite (a plastic) and lignofole (a wood-plastic) have found wide use as bronze and babbitt substitutes in the shipbuilding industry.

Plastics and wood-plastics possess high antifriction properties, a low coefficient of friction, and relatively high wearability. Their primary shortcoming is their low heat conductivity, making it necessary to water-cool bearings made of this material. If sufficiently well cooled, plastic and wood-plastic may be subjected to severe conditions and impact loads.

The maximum physical stresses to which plastics and wood-plastics used as substitutes for babbitts may be subjected have not been fully determined. In practice, textolite operates well up to a specific pressure of 300 kilograms per square centimeter and a sliding speed of 5 meters per second. Lignofole gives satisfactory service up to a specific pressure of 150 kilograms per square centimeter and a sliding speed of 5 meters per second.

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